AD-A268 255

ARMY RESEARCH LABORATORY

ALBEDOS

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ARL-TR-57

July 1993

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1993

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
ALBEDOS

5. FUNDING NUMBERS
61102-B53A

6. AUTHOR(S)
Frank V. Hansen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Battlefield Environment Directorate
ATTN: AMSRL-BE-S
White Sands Missile Range, NM 88002-5501

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-57

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1145

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The albedo of the earth's surface varies dramatically from values of about 3 to 4 percent for calm bodies of water up to about 55 percent for gypsum sands. This rather broad range of reflected incoming solar radiation presents difficulties when attempting to define an average albedo for terrain over a large region from locally determined values. The patchwork, or checkerboard, appearance of the earth's surface as viewed from above is the result of various human activities, such as agriculture, the proliferation of urban sprawl, and road building. Each of these variable appearing surfaces will have individual albedos, rendering any attempt to determine an areal albedo almost an impossibility on the mesoscale. However, a vast data base exists for microscale applications for individual acreages, for example. A compilation of these data is presented.

14. SUBJECT TERMS
albedo, solar radiation, crops, urban areas, land uses.

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	**Unclassified**	**Unclassified**	**SAR**

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

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1. Introduction

The albedo of the earth is usually expressed as a ratio of reflected electromagnetic radiation to the amount incident upon the surface, typically given as a percentage. The aggregate albedo of the earth is, of course, made up of an almost infinite number of albedos of distinct, individual surfaces that comprise its entirety. The albedo of these individual surfaces will vary in time throughout the daylight hours as a function of the solar zenith angle. However, most studies concerned with albedos usually reflect measured values observed near local noon.

An excellent physical survey of seasonal albedos of North America was reported by Kung, Bryson, and Lenschow (1964). The study produced a comprehensive set of maps that delineated areas of regional albedos, that is, averages over several hundred to several thousand square kilometers. The intent of this study was to compile a listing of albedos of individual crops, land use categories, and man-made surfaces.

2. Solar Elevation Angle and Seasonal Effects Upon Albedos

According to Paltridge and Platt (1976), parameterization of a mosaic average surface albedo is a fairly inaccurate process because of the microscale patchiness of the earth's surface. The checkerboard patterns of the surface preclude establishing with any degree of accuracy a typical albedo for a region with a sizable area, even with presently available data, except for the Kung et al. (1964) study.

The actual time-dependent value of the albedo α_g as a function of the solar elevation angle may be of the same form for all surfaces. A first approximation shows that, for most surfaces, α_g is a reasonably constant value down to solar elevations of about 50 degrees and then rapidly increases at smaller values of Θ. Again, most surfaces exhibit the dominant Fresnel reflection characteristic, that is, specular reflection from a smooth surface.

Paltridge and Platt state that it is quite justifiable to assume that a single formula based upon an albedo at high solar elevation angles is valid to estimate the time-dependent albedo. The equation is generally written as

$$\alpha_g(\Theta) = \alpha_l + (1 - \alpha_l)\exp\left[-k(90^\circ - \Theta)\right]$$

where α_g is the albedo for Θ, the zenith angle, α_l a measured albedo, and k is approximately 0.1. Figure 1 demonstrates the use of the equation.

Kondratyev (1969) has also presented some evidence of the diurnal change in observed albedos (figure 2). Kondratyev also investigated the albedo regime as a function of surface conditions and month of the year. Figure 3 shows the annual course of the albedo. Kung et al. (1964), in the portion of their study devoted to the state of Wisconsin, divided the state into 50 sections based upon land use categories such as urban, agricultural, or forested, or by soil types. Table 1 presents an abbreviated listing of representative land use categories 1. Twelve overflights were made on the same flight path to obtain monthly albedo measurements. These monthly values corresponding to the land use categories in table 1 are given in table 2 and graphically in figure 4. The differences for the land use categories are quite dramatic, emphasizing Paltridge and Platt's contention that parameterization of surface albedos to form areal averages is an inaccurate process.

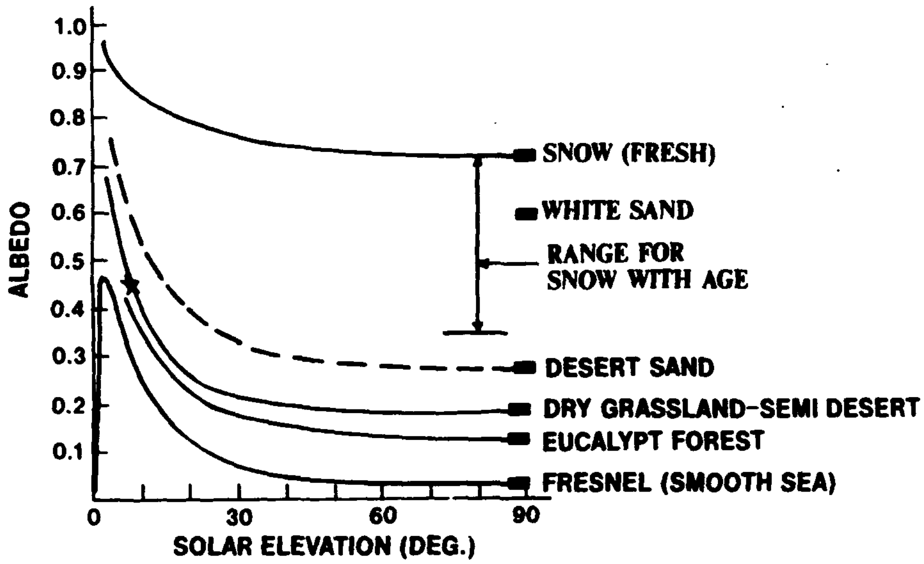

Figure 1. Albedos as a function of solar elevation angle for several surfaces.

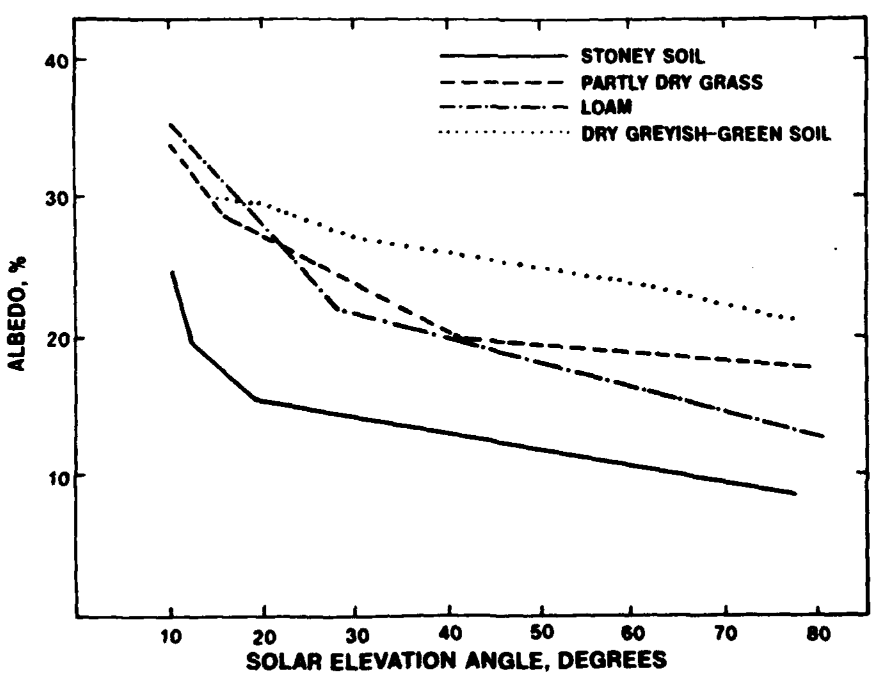

Figure 2. Measured albedos for several surfaces as a function of solar elevation angles.

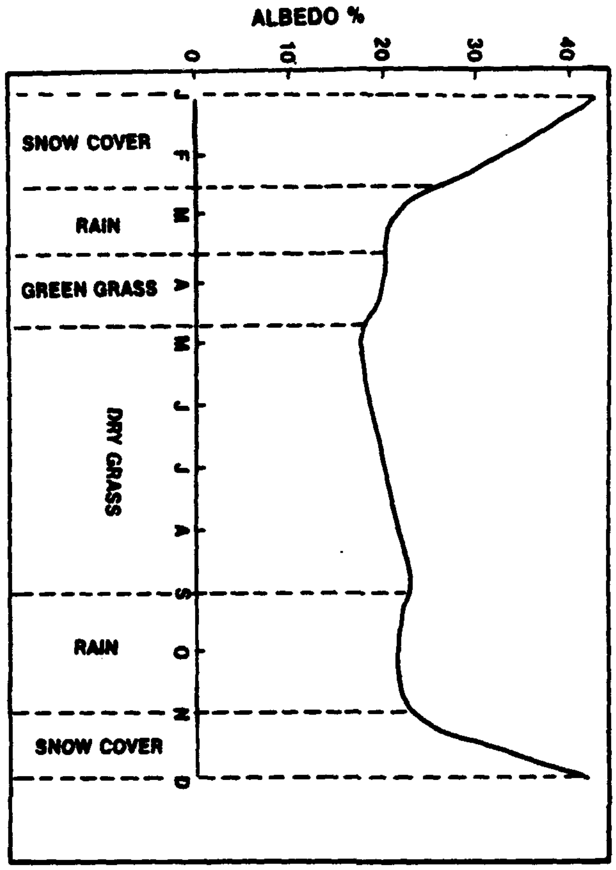

Figure 3. Annual regime of measured albedos as a function of weather conditions.

Table 1. Surface Cover, Land Use Category, Forest Type, and Soils

Section	Surface Use	Soil Type
31	Productive agriculture land, *15%	Sands, grey yellow silt loams
32	Woody agricultural land, northern hardwoods 15 - 50%	Greyish loams
34	Pine forest 40 - 59%	Sands, greyish loams
38	Productive agricultural land 19%	Reddish clay, silt loams, grey loams
43	Productive agricultural land 15%	Reddish clay loams, greyish-brown, and black silt loams
45	Productive agricultural land 15%	

*percent forested

Table 2. Monthly Albedos for Land Use Categories and Soil Types

Section	Surface Characteristics	J	F	M	A	M	J	J	A	S	O	N	D
31	Agricultural land	50.0	48.4	57.5	14.0	13.7	15.0	17.5	16.4	13.9	14.3	13.3	40.6
32	Woody agricultural	38.0	44.8	48.4	14.4	19.5	17.4	16.0	15.4	14.4	13.4	13.6	37.9
34	Pine forest	18.8	20.5	37.6	12.1	23.2	15.8	13.7	13.9	12.7	13.9	9.9	19.2
38	Agricultural land	45.9	51.2	46.9	15.1	16.7	18.4	17.1	15.3	14.5	15.9	13.8	36.4
43	Agricultural land	48.6	38.9	38.3	13.9	20.3	16.5	16.3	17.4	15.0	16.1	14.0	46.0
45	Agricultural land	51.1	37.1	24.3	15.5	12.8	17.0	15.6	17.4	15.1	15.6	13.9	45.2

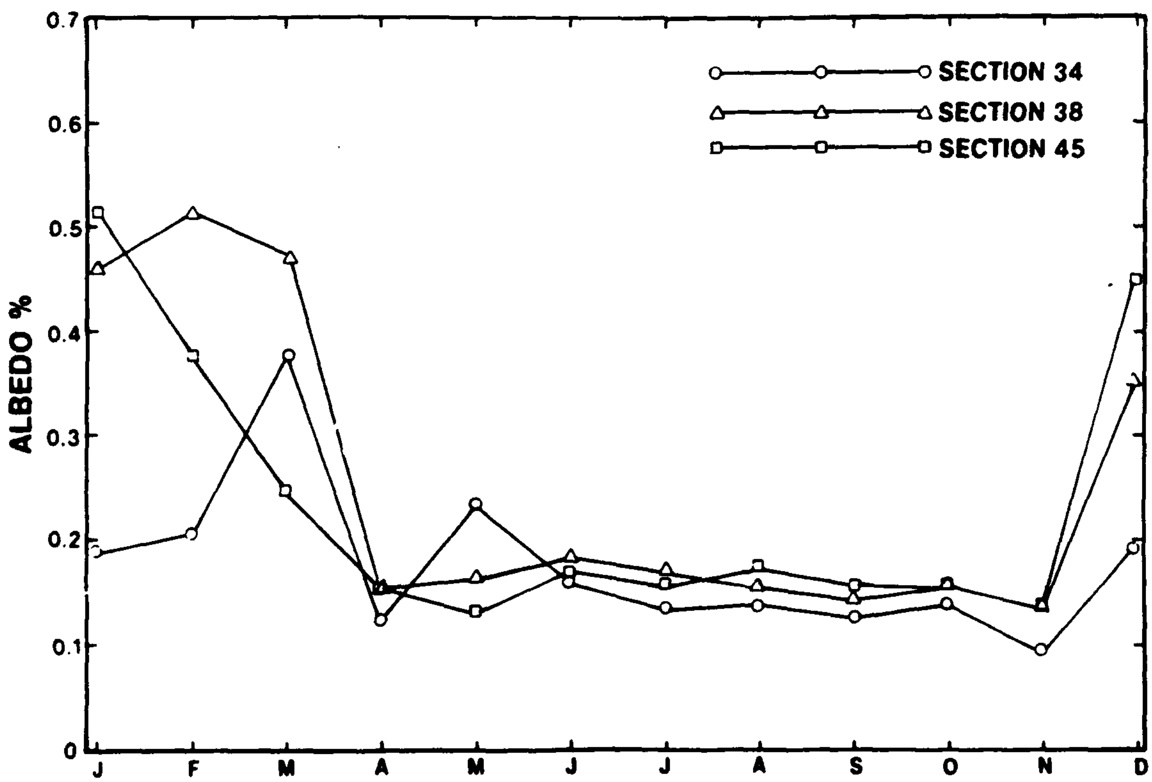

Figure 4. Annual regime of albedo for three Wisconsin flight sectors described by Kung, Bryson, and Lunschow

3. Albedos of the Patchwork Earth

The earth's surface can be classified by land use categories, vegetative cover, and soil types, or by terrain relief. For the purpose at hand, a combination will be used. Five albedo classifications will be explored: water surfaces, bare soils, agricultural crops, natural terrain and vegetations, and urban influences. These data have been compiled from a number of sources and are referenced in the bibliography.

3.1 Water Surfaces

For a smooth water surface, the Fresnel equation may be used. Typical values of the albedo for a water surface are dependent upon the roughness of the surface, that is, a function of wind speed. Other factors that influence water albedos include the turbidity (muddy waters), shallowness of the water body, and the solar elevation angle. Table 3 lists typical albedos for various water surfaces.

Table 3. Albedos of Water Surfaces*

Surface and State	Albedo
Bay	3 - 4
Ocean, deep	3 - 5
Ocean	3 - 7
Inland waters	5 - 10
Bay and river	6 - 10
Troubled waters	7

*Extracted from Kondratyev(1969).

Table 4 represents the solar angle effects upon the albedo for a sea surface and includes the theoretical calculated values as well as two sets of observations by Kazmin and Ångström as reported by Kondratyev (1969). The spread in the observed values can be attributed to the state of the sea surface since Ångström's data were tabulated for troubled waters.*

According to Robinson (1966), part of the discrepancy between the calculated and observed albedos can be attributed to a portion of the reflected diffuse insolation mixed with the reflected solar radiation. A third factor considered was the transmissivity of water and the refractive index of water.

*Ångström's failed to list the albedo for the bridge over troubled waters.

Table 4. Calculated and Observed Albedos Over an Ocean*

Solar Elevation Angle	Calculated (Fresnel)	*Kuzmin	*Ångström
90	2	-	-
70	2	-	-
50	2.5	-	-
30	6	6	8
25	9	8	10
20	14	12	15
15	21	18	28
10	35	32	49
8	43	40	56
6	53	48	70
4	65	60	-

*See *Kondratyev(1969).*

3.2 Bare Soils

The Unified Soil Classification System (USCS) (see Dornbusch 1982) considers soils to be an all-inclusive term and covers a range from muck and peat to solid rock. Thus, bare soils will include the albedos of rock. The term soil can be defined with respect to color, porosity, grain sizes, and the volumetric water content. The moisture content of soils has a profound effect upon the albedo of sand (figure 5). The curve in figure 5 represents a volumetric water content from saturation through field capacity, the wilting point, and a totally dry surface. Table 5 lists the albedos of a number of soils ranging from wet dark soils to dry sands and rock surfaces. The albedo of the various soils decreases with an increasing amount of moisture because the albedo of water is lower than that of soil.

3.3 Agricultural Crops

Albedos related to agricultural activities range from the wintertime condition of fallow fields to the pale greens of headed-out lettuce and Lucerne, more commonly known as alfalfa. Crop albedos are listed in table 6. The range of such entries as fallow fields, dry, and spring wheat are most certainly for early season and late season values. The albedos that have smaller ranges are apparently for different solar angles during the daylight hours, especially those listed for the alfalfa crops. If rice were not raised in flooded fields or paddies, undoubtedly this crop would have a much higher albedo.

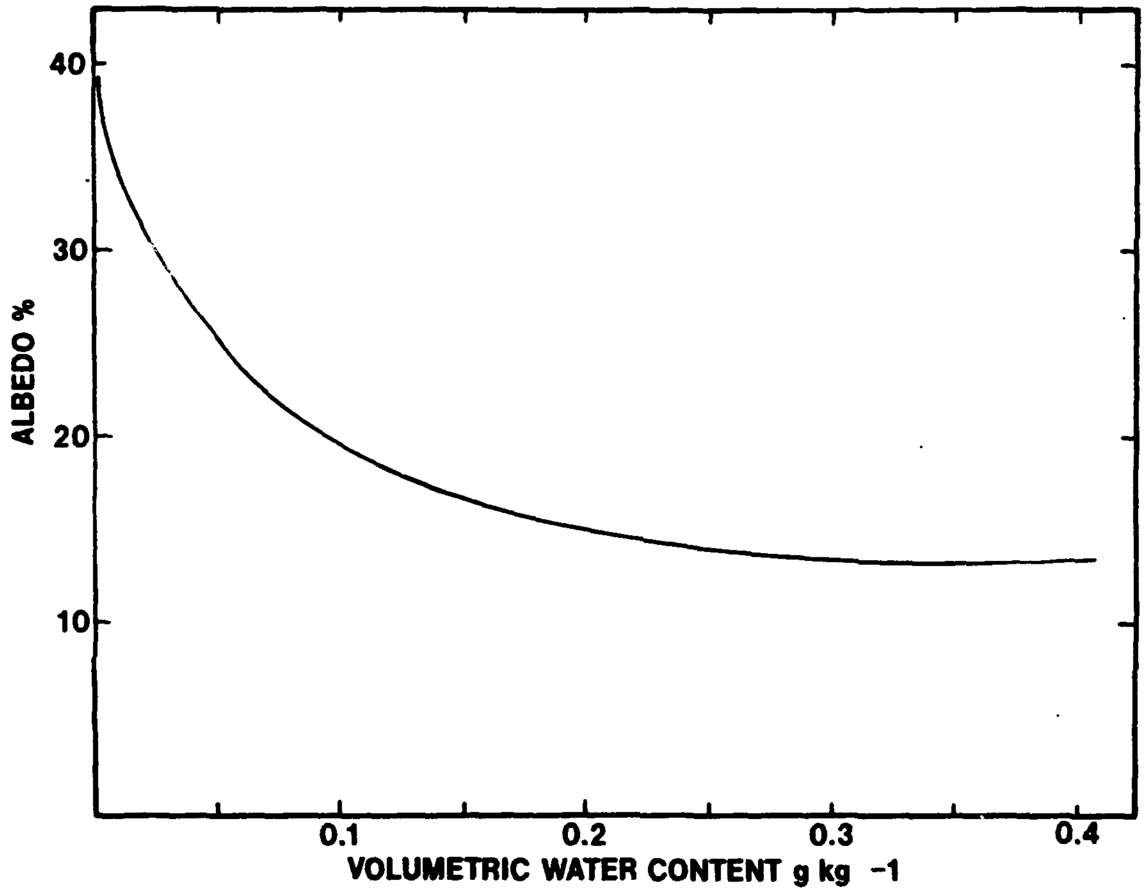

Figure 5. Albedo of bare sand as a function of volumetric water context and the three types of drying.

Table 5. Albedo Values for Various Soils*

Type of Soil	Albedo	Type of Soil	Albedo
Wet fields, not plowed	5 - 14	Blue clay, dry	23
Soil, dark, plowed, wet	6	Clay, dry	23
Black soil, moist	8	Grey soil, dry	25 - 30
Soil, dark, plowed, dry	8	Sand, light, dry	25 - 45
Soil, dark, wet	8	Soil, sandy, dry	25
Soil, light, plowed, wet	8	River sand, quartz, wet	29
Soil, light, wet	10	Sand, quartz, yellow	34 - 35
Soil, grey, mist	10 - 20	Sand, white	34 - 40
Plowed fields, dry	12 - 20	Sand, yellow	35
Dark grey silt	12	Sand, light, fine	37
Soil, dark, dry	13	Sand, dry	40
Black soil, dry	14	River sand	43
Plowed fields, moist	14	White chalk, lime	45
Rust red soil	15	Salt deposits, (playas)	50
Blue loam, moist	16	Sand, gypsum	55
Blue clay, wet	16		
Soil, light, plowed, dry	16	Rocks	
Brown soil	17		
Red soils	17	Lava	10
Reddish brown soil	17	Other rocks	12 - 15
Soil, light, dry	18	Granite	12 - 18
Soil, sand, wet	20	Rocks, wet	20
Soil, clay, dry	20 - 35	Stone	30
Blue loam, dry	23	Rocks, dry	35

*Extracted from Sellers(1965), Robinson (1966), Middleton (1953), Paltridge and Platt (1976).

Table 6. Crop Albedos*

Crop Type	Albedo	Crop Type	Albedo
Fallow field, wet	5 - 7	Beets	18
Fallow field, dry	8 - 12	Maize	18
Spring wheat	10 - 25	Wheat	18
Swamp rice	11	Tobacco	19
Paddy rice	12	Cassava	19
Kola nuts	13	Potatos	19
Stubble fields	15 - 17	Yams	19
Sugar cane	15	Cotton	20 - 22
Winter wheat	16 - 23	Rye	20
Cocoa	16	Sorghum	20
Ground nuts	17	Lettuce	22
Winter rye	18 - 23	Alfalfa (start of blossoming)	23 - 32

*Extracted from Pielke (1984), Sellers (1965), Kondratyev (1969).

3.4 Natural Terrain and Vegetations

In nature, ground cover ranges from virgin coniferous forests to arid desert lands with little or no vegetation. Included in this classification will be snow and ice-covered surfaces as well as snow and vegetation mixes. Table 7 shows that time of day, solar angle, and season of the year enter into these evaluations of the albedos of natural terrain and vegetation. The table also shows that dry season or drought conditions affect surface albedos. One of the best reflecting surfaces appears to be deciduous forests, during summer and fall, with an albedo of 16 to 27 and 33 to 38, respectively.

Snow and ice-covered surfaces typically have the highest reflective powers of all (table 8). Kondratyev (1969) has pointed out that the albedo of snow will vary markedly with solar elevation angle, cloud cover, and season. The albedos for old and freshly fallen snow represent clear sky values for elevation angles of 5 to 45 degrees. Figure 6 demonstrates seasonal variability for a period from late winter through early spring. Generally, rain forests are thought of as being tropical or subtropical phenomena. However, the coniferous forests of the Olympic Peninsula in the state of Washington are considered to be rain forests. The low albedo of this region in winter may be attributed to the mild climate and the snow shedding abilities of the Douglas fir.

Table 7. Albedos of Natural Terrain and Vegetation*

Terrain or Vegetation	Albedo	Terrain or Vegetation	Albedo
Forest, coniferous	5 - 15	High grass, dense	18 - 20
Forest, pine	6 - 19	Deciduous trees, growing	18
Grass, green	8 - 27	Tall grass, growing	18
Forest, deciduous	10 - 20	Oak crowns	18
Meadows, green	10 - 20	Mowed grass, dormant	19
Fir tree, crowns	10	Sun dried grass	19
Heather wasteland	10	Guinea savanna	19
Coniferous trees, dormant	12	Sand dunes, wet	20 - 30
Deciduous trees, dormant	12	Steppe	20
Tropical rain forest	12	Bahama grass	21
Tall grass, dormant	13	Desert	25 - 30
Coniferous trees	14	Savanna, dry season	25 - 30
Pine tree crowns	14	Green grass	26
Spruce crowns	14	Mowed grass, growing	26
Chaparral	15 - 20	Clayey desert	29 - 31
Savanna, wet season	15 - 20	Loamy desert	29 - 31
Tundra	15 - 20	Desert	30
Sudan savanna	15	Deciduous forest, autumn	33 - 38
Deciduous forest, growing	16 - 27	Sand dune, dry	35 - 45

*Extracted from Sellers (1965), Tooming (1960), Paltridge and Platt (1976), Kondratyev (1969) and Robinson (1966).

Table 8. Ice and Snow Covered Natural Surfaces*

Surface Condition	Albedo	Surface Condition	Albedo
White porous sea ice	12	Snow, fresh fallen snow-covered vegetation	75 - 95
Water covered ice sheet	26	Rain forests	16
Sea ice, milky blue	30 - 40	Desert shrublands	18 - 19
Thawing snow	30 - 65	Crops and woodlands	18 - 19
Ice, light snow cover	31	Mixed forest, 50 cm snow	20
Old snow	40 - 70	Great basin shrublands	29 - 38
Porous ice, melting	41	Forest and grassland	46 - 50
Ice, grey	60	Tundra and conifer forest	59 - 67
Ice, white	75	Tundra	83
Icy snow	75		

*Extracted from Kondratyev (1969), Kazmin (1957), and Robinson (1966).

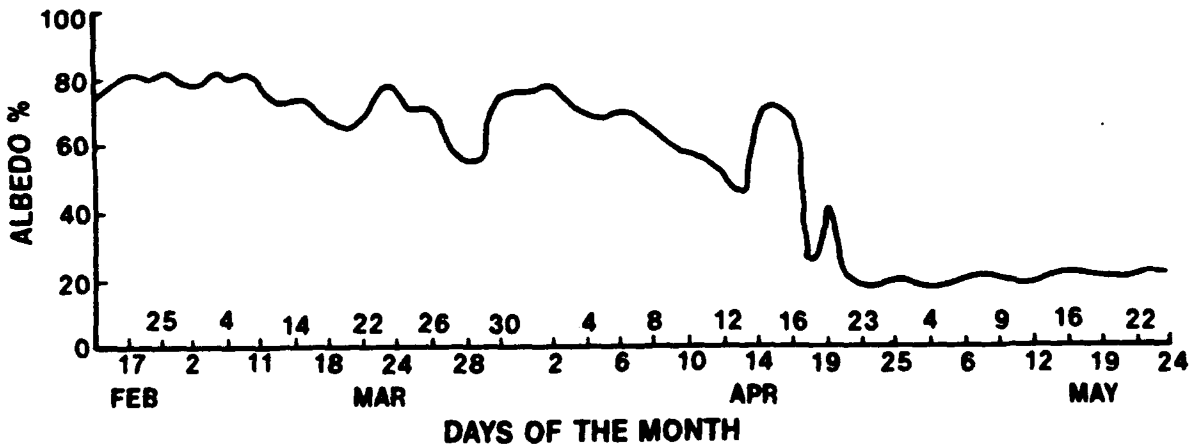

Figure 6. The albedo for a surface in late winter and early spring as snow cover diminishes.

3.5 Urban Influences

Urban sprawl has a definite influence upon earthly albedos. Included in this category are items such as dirt roads as well as paving and building materials. Table 9 is devoted to urban albedos. Roadway and paving materials show the most variability in an urban setting, especially for concrete. The fairly low albedo listed for service station paving is undoubtedly due to crankcase drippings on the surface as opposed to an albedo of 37 for new, white concrete. The albedo range of 17 to 27 for dry concrete is indicative of an artificial aging process caused by drippings and rubber particles adhering to the surface as the traffic count increases with usage.

Kung et al. (1964) have summarized the surface albedos of a number of cities and the surrounding suburban areas. This material is reproduced in table 10. The average albedo of cities and towns appears to be 16 with a range from 12.1 for Zanesville, Ohio, to 22.9 for Gila Bend, Arizona. Suburban values range from 11.4 for Waycross, Georgia, to 26.5 for Las Vegas, Nevada, with an average of 16.5 not significantly different from city cores. The December data for Madison, Wisconsin, was omitted because of obvious snow cover influences. The albedos for Gila Bend, Arizona, and the suburban values for Las Vegas, Nevada, obviously reflect the influences of a desert climate, while the low values for suburban Waycross, Georgia, can probably be accounted for by the presence of many tree-shaded streets.

Table 9. Urban and People-Influenced Albedos*

Surface or Material	Albedo	Surface or Material	Albedo
Road, blacktop	5 - 10	Asphalt road, dry	15
Blacktop, supermarket parking lot	8	Concrete in service station	15
		Light granite chips	15
Dirty tiled roof	8	Thatched roof, old	15
Buildings	9	Corrugated iron roof, new	16
Asphalt	10	Concrete, dry	17 - 27
Asphalt road, wet	10	Dirt road, wet	18
Corrugated iron roof, rusty	10	Clay road, wet	20
		Thatched roof, new	20
Dirty mastic asphalt roof	12	Limestone tiles	25
Blacktop road	14	Clay road, dry	30
Corrugated iron roof, fairly new	14	Concrete	30
		Dirt, road, dry	35
Artificial stone paving	15	New, white concrete	37

*Extracted from List (1958), Newrocki and Papa (1963), Pielke (1984), and Shapiro (1982).

Table 10. Surface Albedo of Town and Suburb in Various Cities

City	Date (1963)	Surface albedo	
		Town	Suburb
Madison, WI	Feb 21	15.4	17.9
Madison, WI	Mar 21	15.2	12.9
Madison, WI	Apr 11	16.3	14.7
Madison, WI	Jun 12	14.9	15.0
Madison, WI	Sep 26	15.9	14.2
Madison, WI	Nov 19	17.8	13.9
Ogden, UT	Jun 30	15.6	16.6 (salt flat)
Boise, MT	Jul 1	17.0	18.7 (irrigated field)
Wausau, WI	Jul 18	13.1	15.5
Duluth, MN	Jul 18	12.4	16.2
Winnipeg, Manitoba	Jul 18	15.9	13.0
Grand Forks, ND	Jul 21	14.0	15.9
Las Vegas, NV	Sep 6	19.5	26.5 (desert)
Yuma, AZ	Sep 6	20.0	19.4
Gila Bend, AZ	Sep 6	22.9	23.5
Tucson, AZ	Sep 6	22.0	20.4
San Antonio, TX	Sep 7	18.1	16.7
Houston, TX	Sep 7	----	16.6
Port Arthur, TX	Sep 7	16.5	15.7
Mobile, AL	Sep 8	14.0	13.1
Miami, FL	Sep 9	17.7	14.1
Jacksonville, FL	Sep 9	----	15.1
Waycross, GA	Sep 9	15.2	11.4
Jessup, GA	Sep 9	14.5	11.6
Washington, D.C.	Sep 10	12.5	13.1
Zanesville, OH	Sep 10	12.1	15.1
Columbus, OH	Sep 10	13.7	16.1
Cincinnati, OH	Sep 10	13.0	15.3
Bloomington, IN	Sep 10	16.8	14.7
Champaign-Urbana, IL	Sep 10	16.6	16.0

4. Conclusions

The characteristic checkerboard appearance of the earth's surface in all seasons of the year precludes forming average values of surface albedos from the typical microscale measurements usually reported on and summarized in section 3. Although this summary is interesting and perhaps useful, the aerial survey by Kung et al. (1964) provides more insight to areal albedos. If more detail is needed on a smaller scale, then a land use categorization scheme would have to be combined with the areal information and the albedos tabulated in tables 3 through 10. In addition, seasonal data would be required as well as cloud cover and solar elevation angle effects.

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